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Environmental Effects of Dredging Technical Notes

A PROCEDURE FOR DETERMINING CAP THICKNESS FOR CAPPING SUBAQUEOUS DREDGED MATERIAL DEPOSITS

PURPOSE: This note presents preliminary information on using a procedure to ascertain the thickness of a cap of natural material necessary to isolate a contaminated sediment under aquatic disposal conditions.

BACKGROUND: When testing required under Public Law 92-532 (the Ocean Dumping Act) demonstrates that aquatic disposal of dredged material may cause unreasonable degradation of the marine environment, ocean disposal of that material may be prohibited. Capping of the contaminated material by material suitable for ocean disposal has been accepted by the Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter (London Dumping Convention) as an alternative to other disposal methods (such as confined land disposal). For this option to be operational (rather than being restricted to experimental situations), it must be demonstrated that capping isolates the contaminated material under a wide range of conditions.

A prime concern about capping as an acceptable disposal method is its efficiency in isolating contaminated dredged material from the water column and from both pelagic and benthic biota. Much work has addressed this concern (Brannon et al. 1985, 1986; Gunnison et al. 1986, 1987; Palermo et al., in preparation). In these studies, the effectiveness of capping in chemically and biologically isolating a contaminated sediment from the overlying water column was studied using a two-step process that involved small- and large-scale experimental units.

The small-scale laboratory tests were used to experimentally assess the cap thickness needed to chemically isolate a contaminated dredged material by following changes of dissolved oxygen, ammonium-nitrogen, and orthophosphate-phosphorus in the overlying water column. The large-scale laboratory tests were used to:

- Determine the effect of cap thickness in preventing movement of contaminants into the biota.
- Determine the effect of bioturbation on the effectiveness of capping.
- Validate results that were obtained in the small-scale test.

Based on the results of these studies, a research procedure has been modified into a laboratory test suitable for field use.

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The effective cap thickness for a biological and chemical seal provides the isolation necessary to control the movement of contaminants out of the contaminated dredged material into the overlying water column and to prevent direct contact (through bioturbation) between aquatic biota and contaminants. This estimated thickness does not allow for hydrodynamic forces that may result in scouring and resuspension of cap material and, possibly, the material beneath the cap. Procedures to predict and offset the effects of hydrodynamic processes require engineering considerations. In addition, since capping is still considered an experimental procedure under some water depth and hydrodynamic conditions, the site should be monitored once the cap has been emplaced. For a discussion of such capping-related concerns, see Environmental Laboratory (1987), Truitt (1987a,b), and Palermo et al. (in preparation).

ADDITIONAL INFORMATION AND QUESTIONS: For additional information on the procedure described in this article, contact the authors, Mr. Thomas Sturgis, commercial and FTS (601)634-2805, and Dr. Douglas Gunnison, (601)634-3873, or Dr. Robert M. Engler, Manager of the Environmental Effects of Dredging Programs, (601)634-3624.

Small-Scale Laboratory Test for Field Application

To allow Corps Districts to estimate the cap thickness that will chemically isolate a contaminated sediment from the overlying water column, a laboratory test is needed that is accurate and easily used. Such a test has been developed based on the work of Brannon et al. (1985, 1986), Gunnison et al. (1986), and Palermo et al. (in preparation).

Dissolved oxygen (DO) depletion, ammonium-nitrogen, and orthophosphate-phosphorus are used as tracers because they are easy and inexpensive to measure. A cap thickness that is effective in preventing the movement of these inorganic constituents will also be effective in preventing the movement of organic contaminants that are more strongly bound to sediment (e.g., polynuclear aromatic hydrocarbons (PAHs), petroleum hydrocarbons, and polychlorinated biphenyls (PCBs)). The behavior of soluble reduced inorganic species (e.g., arsenic) will also be similar to the tracers.

Dissolved oxygen depletion in the water column is normally not a problem in an open-water disposal environment, due to mixing and reaeration of the water column. However, DO depletion can be used as a tracer for determining the effectiveness of a cap in isolating an underlying contaminated dredged material having an oxygen demand exceeding that of the capping material. A cap thickness that is effective in preventing or reducing the diffusion of DO into the contaminated sediment will also prevent or reduce the diffusion of DO-demanding species from the contaminated sediment into the overlying water

column. Once an effective cap thickness has been achieved, there will be no significant difference in oxygen depletion rates between the contaminated sediment with cap material and the cap material alone.

A similar rationale is applicable for using ammonium-nitrogen and orthophosphate-phosphorus as tracers. These constituents are released only under anaerobic conditions. However, if the layer of cap material is thick enough to prevent the diffusing materials in the underlying contaminated dredged material from reaching the water column, the release rates from the capped contaminated sediment will be the same as from the cap material alone.

Chemical tracers

More than one tracer (ammonium-nitrogen, orthophosphate-phosphorus, and DO depletion) should be considered for each application (Brannon et al. 1985, 1986; Gunnison et al. 1986; Palermo et al., in preparation). In a laboratory study conducted with dredged material from Everett Harbor, Washington, the DO depletion rate of the cap material was not significantly different from that of the contaminated sediment (Palermo et al., in preparation). This precluded the use of DO depletion as a tracer in evaluating cap effectiveness. In studies using sediments from Dutch Kills, New York, and Black Rock Harbor, Connecticut, orthophosphate-phosphorus was unsuitable as a tracer, while DO depletion and ammonium-nitrogen were suitable (Brannon et al. 1985, 1986; Gunnison et al. 1986).

Another reason for using more than one tracer is the variation of chemical and biochemical properties in sediments. Frequently, the contaminated sediment and the proposed capping material will be so different that a chemical property of the contaminated sediment will be easily distinguishable from that same property of the cap material. However, when the cap material has chemical properties similar to the contaminated sediment, chemical differences are harder to distinguish. In such a case, if only one tracer is measured and negative results are obtained, a second series of tests is necessary.

Water analysis

The release rates of ammonium-nitrogen and orthophosphate-phosphorus should be determined in accordance with procedures recommended by Ballinger (1979).

The depletion rate of DO should be determined using either the azide modification of the Winkler method, as described in Standard Methods (APHA 1986), or a DO meter.

Sediment collection

Samples of contaminated sediment should be collected that are representative of sediment to be dredged. Samples of the proposed capping material should also be taken. To ensure that sediment samples are not diluted with large volumes of water, a clamshell dredge or similar device should be used to sample both contaminated sediment and capping material. Representative subsamples of both materials should be taken for initial bulk analysis and characterization. All sediments should be placed into polyethylene-lined steel barrels, sealed, and stored at 4° C until tested.

Sediment preparation

Sediment samples should be composited and mixed, using a motorized mixer (to ensure a homogenous sediment sample). Any unused sediment may be returned to the containers, stored at 4° C, and later discarded if there is no further need for the sediment.

Handling of highly contaminated sediments

The following procedure, which outlines safety equipment, sediment handling, cleanup operations, and disposal, is used by the Environmental Laboratory for handling highly contaminated sediment. This procedure is not intended to replace any existing procedures; however, it can serve as a guide and supplement the existing safety procedures.

All individuals involved in handling contaminated sediment are required to use protective equipment and to submit to blood and urine tests. The protective equipment consists of:

- A full-face chemical cartridge respirator (with an organic chemical cartridge and dust filter).
- A pressure-demand airline respirator, when handling sediment with PCB concentrations $\geq$2,500 ppm.
- A polyethylene- or saran-coated tyvek disposable coverall.
- Inner PVC laboratory gloves with outer neoprene gloves.
- Neoprene rubber boots.
- Surgical scrubs.

Blood and urine sampling is intended as a monitoring procedure to ensure the safety of the individual handling the sediment. It is recommended that background blood and urine screening be performed for those contaminants of concern before project testing begins and upon completion of the project. In cases of exposure to highly contaminated sediment over a long period (6 months

or longer), blood and urine sampling should be done every 3 months.

Contaminated sediment must be handled in a well-ventilated building in order to control the concentration of particles in the air. For example, PCBs will adsorb strongly to any surface, and a small amount of contaminated sediment solids in the air can have very high concentrations of PCBs adsorbed on them, making inhalation of this dust very dangerous. Also, polyethylene sheeting should be placed under all test and mixing apparatus as a contamination preventive measure. This polyethylene sheeting will prevent needless contact with the laboratory surface and make cleanup easier.

Cleanup is an essential part of a safe laboratory environment. The procedure is as follows:

- Contaminated sediment should be removed from all equipment using machine wipes. Used wipes are considered hazardous and should be disposed of in the same manner as coveralls (see below).
- All equipment is rinsed in the laboratory sink after cleaning. The sink is then thoroughly cleaned.
- The polyethylene sheeting is disposed of in a disposal drum.
- Lids are fastened securely on the drums.
- Coveralls (used as protective clothing) and surgical scrubs (worn underneath the coverall rather than personal clothing) are removed and placed in a disposal drum.
- The disposal drum is labeled and disposed of according to US Department of Transportation guidelines (1984).

Materials

The following items are required to conduct the laboratory test:

- Twelve 22.6-ℓ cylindrical plexiglass units, 120 cm in height and 15.5 cm in diameter attached to a 30-cm, 2-plexiglass base (see Figure 1). The units should be fitted with a sampling port.
- Twelve plexiglass plungers, 80 cm in length with a wire hook attached at the top.
- Twelve pint-size bottles of mineral oil.
- Six aquarium pumps (two small-scale units per pump) or some other source of air supply.
- Twelve 1-cm-long airstones.
- Two plexiglass tubes, 130 cm in length, 7.28-cm inside diameter.
- Two large funnels, 40.8-cm top diameter, 6.60-cm outside diameter at the base.
- Tygon tubing, 3.02-mm inside diameter.

Test procedure

Step 1 - Adding contaminated sediment to the units. The contaminated sediment should be mixed, then placed in the bottom of nine small-scale units to a depth of 10 cm (Figure 1). It is important to add the sediment carefully to avoid splashing on the sides of the units.

Step 2 - Adding capping material. The capping material is mixed and then added in thicknesses of 22 and 35 cm in triplicate to six of the units

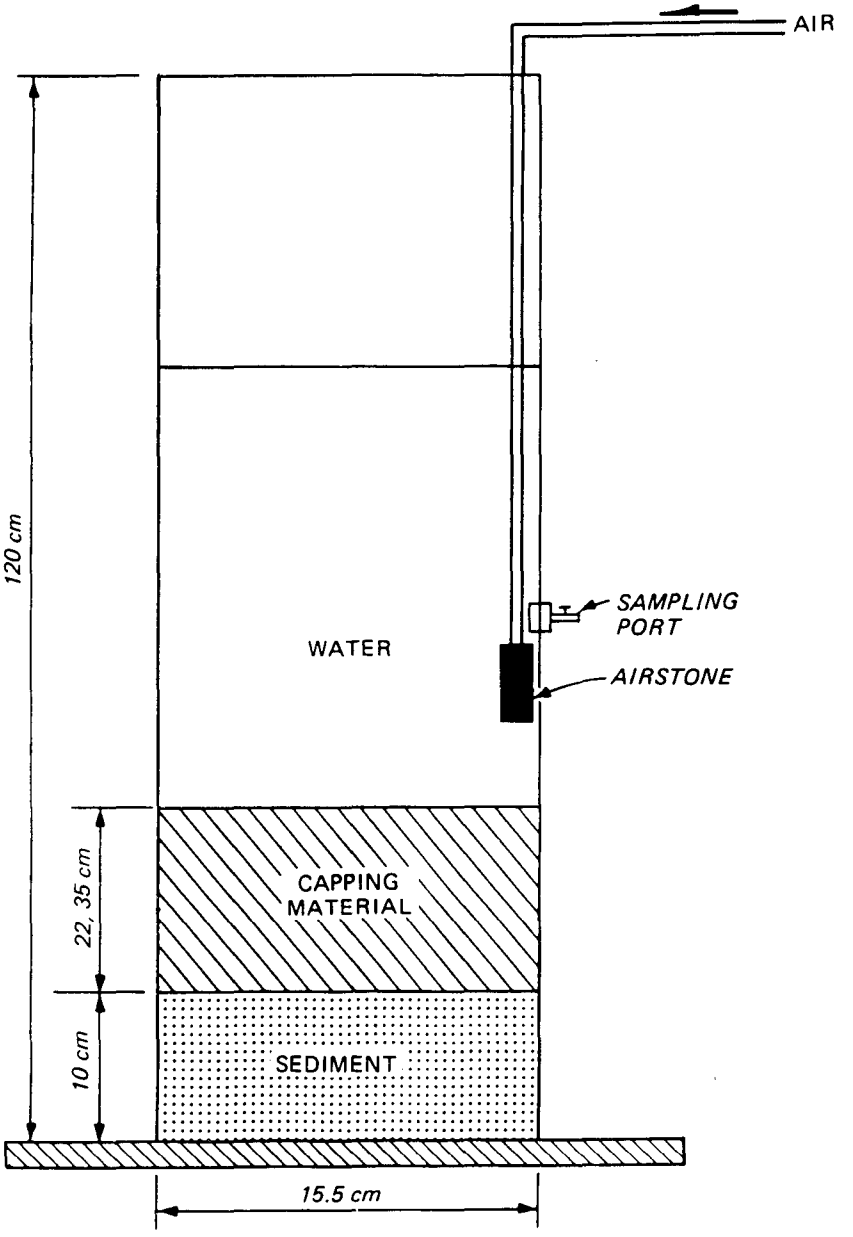

Figure 1. Small-scale experimental unit

containing the contaminated sediment (Figure 1). The remaining three units with contaminated sediment receive no cap. An additional three units receive 10 cm each of capping material only. Units containing contaminated sediment alone and units with capping material alone serve as controls. The 22- and 35-cm cap thicknesses were selected based on results of studies conducted by Brannon et al. (1985, 1986) and Gunnison et al. (1986). The experimental setup for the small-scale laboratory test is shown in the following table:

Small-Scale Units	Sediment
1-3	Contaminated sediment only
4-6	Cap material only
7-9	Contaminated sediment + 22-cm cap
10-12	Contaminated sediment + 35-cm cap

Step 3 - Water addition and unit aeration. For an estuarine or marine simulation, 10 ℓ of artificial seawater is prepared using artificial sea salts to achieve the salinity of the proposed disposal area. For a freshwater simulation, 10 ℓ of either distilled or reverse osmosis water is used. The water is added as gently as possible to each small-scale unit and allowed to equilibrate for 3 days while being aerated. Aeration will ensure that the DO concentration in all units is at or near saturation (within ±0.5 mg/ℓ) at the start of the test.

After 3 days of aeration, the airstone is removed, and a plunger and mineral oil are added. The plunger is used for daily mixing to prevent the establishment of concentration gradients in the water column and to ensure a well-mixed column. Mineral oil is used to seal the surface of the water column from the atmosphere to allow the development of anaerobic conditions in the water column. The plunger is suspended between the sediment and the mineral oil. Mixing should be done in a manner that will not disturb the sediment in the bottom of the unit or breach the mineral oil on the surface of the water. After mixing, the plunger is left suspended in the water column.

Step 4 - DO measurements. Water samples should be taken immediately after aeration for initial DO determination. Dissolved oxygen should then be measured daily until the DO is depleted in the water column of the uncapped contaminated sediment. The consequences of reducing the volume of the water column by taking DO samples is accounted for by multiplying the DO

concentration (milligrams per liter) by the volume of water remaining in the unit after a given sampling. (See the Calculations section that follows.)

Step 5 - Water sampling and preservation. Water samples to be analyzed for ammonium-nitrogen and orthophosphate-phosphorus should be taken immediately after the DO is depleted (day 0) and subsequently on days 15 and 30. These water samples should be cleared of particulate matter by passing through a 0.45- m membrane filter, preserved by acidification with concentrated hydrochloric acid (HCl) to pH 2, then stored at 4° C. After the water column is sampled on day 30, all water samples (days 0, 15, and 30) should be analyzed. Results from previous small-scale studies (Brannon et al. 1985, 1986; Gunnison et al. 1986; Palermo et al., in preparation), have shown that complete anaerobic conditions are achieved in the water column within 30 days.

Data interpretation and analyses

The results from these laboratory tests will indicate which of the thicknesses (22 or 35 cm) will reduce overlying-water oxygen demand and transfer of ammonium-nitrogen and orthophosphate-phosphorus from the contaminated sediment to the level of the cap material alone.

Oxygen-depletion rates and ammonium-nitrogen and orthophosphate-phosphorus release rates should be determined by performing linear regression analyses of mass uptake or release per unit area (milligrams per square meter) versus time. Means and standard deviations should be determined for the triplicates, and t-tests should be conducted to determine the statistical significance of differences between the means. Rates plotted are the means and standard deviation of three replicates and represent values greater than the controls.

Calculations

The rates in this test are defined as milligrams per square meter per day. This may be determined by:

$$Tt = Pd \times Vr$$

then

$$Ra = Tt/Au/day$$

where

Tt = tracer total concentration (mg) in the unit

Pd = tracer dissolved concentration (mg/ml) as determined by chemical analysis

Vr = volume of water (ml) remaining in the water column after a given sampling

Ra = rate of release or mass uptake ($mg/m^2/day$)

Au = area (m^2) of the unit

day = number of days of study

The recommended thickness (22 or 35 cm) can then be evaluated by comparing the release rates (Ra) of tracers through the thicknesses tested to the release rates of tracers from the capping material alone. For a given thickness to be considered effective, its release rates must equal those from the capping material alone, or there should be no statistically significant difference.

Figure 2 is an example graph showing oxygen depletion rates of the Black Rock Harbor sediment capped with sand plotted against cap thickness (centimeters). It is important to note that a series of cap thicknesses ranging from 2 to 26 cm were evaluated. The data points on the graph are means and standard deviations of three replicates. Results show that a 22-cm cap of

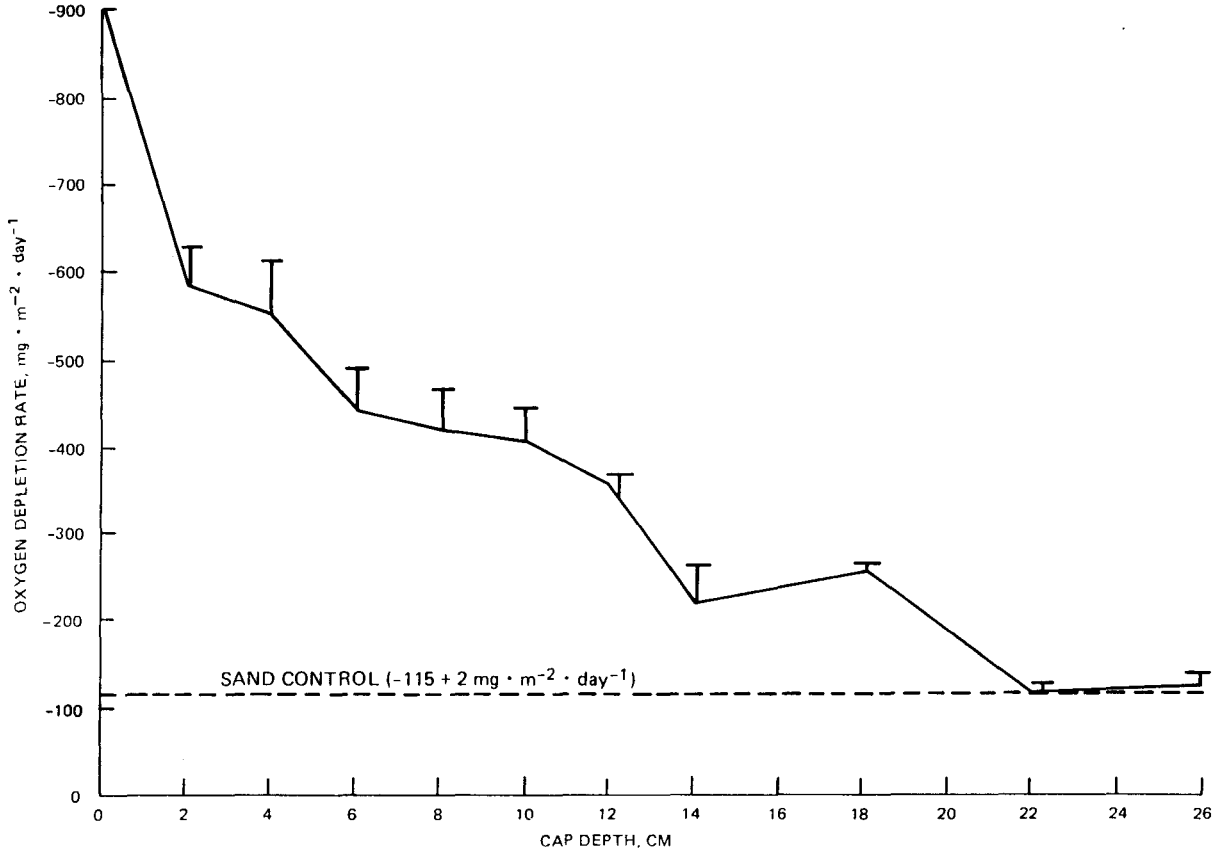

Figure 2. Effect of sand cap depth on overlying water oxygen demand

sand resulted in inhibition of oxygen demand equal to that of the sand cap itself, thus indicating a seal effective in isolating the overlying water column from oxygen demand due to Black Rock Harbor sediment. In this case, the recommended thickness for reducing oxygen demand on the overlying water by the contaminated sediment would be 22 cm.

The test described here will evaluate only the 22- and 35-cm thicknesses of caps. An alternative to using two capping thicknesses is to conduct a series of tests using capping thicknesses ranging from 2 to x cm. Through this approach, the effective cap thickness to chemically isolate the contaminated sediment can be determined.

The thickness predicted by this test is for a chemical seal only and does not include allowances for bioturbation.

Bioturbation

The importance of bioturbation by burrowing aquatic organisms to the mobility of contaminants cannot be overestimated. In addition to the disruption (breaching) of a thin cap that can result when organisms actively work the surface sediments, there is the problem of the direct exposure of the burrowing organisms to the underlying contaminated sediment.

The thickness needed to prevent breaching of cap integrity through bioturbation can be determined indirectly from other information sources. For example, the benthic biota of US coastal and freshwater areas have been fairly well examined, and estimates of the depth to which benthic animals burrow should be available from regional authorities.

Estimating required cap thickness

The thickness required to obtain a complete chemical and biological seal (TR) is provided by the equation:

$$TR = TP + DB$$

where

TP = predicted thickness (cm) to obtain a chemical seal

DB = depth (cm) to which the deepest burrowing organism in the region can reach (obtained by consultation with authorities or bioturbation in the region)

A cap thickness is needed that will maintain its efficacy under the long-term effects of hydrodynamic forces. The hydrodynamic forces may result

in erosion and transport of the cap material, thus reducing the efficacy of the cap. If hydrodynamic forces are severe enough, other precautions, such as armoring cap surface, may need to be taken. For additional information on engineering considerations to offset hydrodynamic forces, see Truitt (1987a,b).

References describing the application of both the small- and large-scale tests to several Corps projects are available in Brannon et al. (1985, 1986), Gunnison et al. (1986), Environmental Laboratory (1987), and Palermo et al. (in preparation). A detailed description of the development of the small-scale test is given in Gunnison et al. (1987).

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Environmental Effects of Dredging Technical Notes

The Environmental Effects of Dredging Technical Notes have been published since June 1985, and the reaction from the field offices has been very encouraging. The responses have noted quality and timeliness of subject matter, and ease of keeping up with new and innovative ideas in dredging-related areas.

Although the primary distribution is to the field offices of the Corps of Engineers for use by personnel involved with all aspects of dredging and disposal projects, these Technical Notes are not just "WES to Field." They are intended to include "Field to WES" and "Field to Field." Field input is highly desirable to disseminate to other offices new techniques or a unique application developed by Corps field offices. WES will collect and publish appropriate material and fully credit the source. Every Corps professional involved in dredging projects in the Corps of Engineers is a partner in the Technical Notes and is encouraged to contribute.

The information presented in the Technical Notes is based on state-of-the-science procedures and state-of-the-practice field demonstrations. However, these are considered interim in nature. Consequently, they may not be final procedures or approaches in all cases. Engineer Manuals and other implementation manuals will provide the more formal guidance.

Suggestions on subject material and input from the Corps field for Technical Notes are invited and should be addressed to Commander and Director, US Army Engineer Waterways Experiment Station, ATTN: CEWES-EP-D, PO Box 631, Vicksburg, MS 39180-0631.

Subject material can be in any of the following areas:

1. Aquatic Disposal
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9. Equipment